JC05 Rec'd PCT/PTO 19 SEP 2005
10/550116

DESCRIPTION

BRANCHING FILTER AND SURFACE ACOUSTIC WAVE FILTER

Technical Field

The present invention relates a branching filter composed of a first filter and second filter, which have different passbands from each other and which are connected to each other, and a surface acoustic wave device used in the branching filter, and more particularly, relates to a branching filter with the structure to improve temperature properties and a surface acoustic wave device used in the branching filter.

Background Art

Heretofore, in communication apparatuses such as a mobile phone, a branching filter composed of a first filter and a second filter has been widely used, the first filter and the second filter having different passbands from each other and being connected to each other. For example, in the following patent document 1, a branching filter having a circuit structure shown in Fig. 17 has been disclosed.

In a branching filter 101, a first filter 103 and a second filter 104 are connected to an input terminal 102. The first filter 103 has a series arm resonator S_{01} and a parallel arm resonator P_{01}, and the second filter 104 has a series arm resonator S_{02} and a parallel arm resonator P_{02}. In this branching filter, the series arm resonators S_{01} and

S_{02} and the parallel arm resonators P_{01} and P_{02} are each formed of a surface acoustic wave resonator. That is, using a surface acoustic wave filter composed of two surface acoustic wave resonators connected to each other, the first filter 103 and the second filter 104 are each formed.

In addition, the first filter 103 has a passband lower than that of the second filter 104 and is used as a transmission filter. On the other hand, the second filter 104 is used as a reception filter.

Furthermore, in the branching filter described in the patent document 1, inductance elements and capacitor elements (not shown) are connected in the first filter 103 and the second filter 104 so as to achieve matching therebetween.

On the other hand, in the following patent document 2, in a surface acoustic wave device in which electrodes are formed on a piezoelectric substrate, a structure to improve temperature properties has been disclosed which is obtained by forming a SiO_2 film having a polarity of a temperature coefficient of frequency opposite to that of a piezoelectric single crystal forming the piezoelectric substrate.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 5-167388

Patent Document 2: Japanese Unexamined Patent Application Publication No. 2-37815

Disclosure of Invention

Incidentally, as a branching filter used in a communication apparatus in which the spacing between the passband of a transmission filter and the passband of a reception filter is extremely small, when the branching filter 101 described in the patent document 1 is used, since the temperature properties of the first filter 103 and that of the second filter 104 are not sufficient, specification properties may not be satisfied in a service temperature range in some cases. In this case, the specification properties represent the frequency properties such as the in-band loss and the amount of attenuation in the first filter 103 and the second filter 104 of the branching filter.

In addition, in the application as described above, when a SiO_2 film is only formed on a piezoelectric substrate in order to improve the temperature properties as is the case of the patent document 2, it has been difficult to sufficiently ensure the specification properties of the branching filter.

In particular, even when a branching filter is used having a small temperature coefficient of frequency by forming a SiO_2 film, for example, in the case of a PCS communication system in which the passband at the transmission side is 1,850 to 1,910 MHz, the passband at the reception side is 1,930 to 1,990 MHz, and an amount of

attenuation of 42 dB or more must be ensured in the passband of the other side filter, there has been a problem in that the specification properties cannot be satisfied.

That is, when the thickness of a SiO_2 film is increased in order to decrease the temperature coefficient of frequency, although the temperature coefficient of frequency is close to zero, by the increase in film thickness of the SiO_2 film, the electromechanical coefficient is decreased, and as a result, the band width is inevitably decreased.

In addition, as a filter forming this type branching filter, a ladder filter has been widely used. As a method for broadening the band width of a ladder filter, a method for broadening the band width toward a low frequency side has been known in which the inductance of an inductance element is increased which is connected in series to a parallel arm resonator forming the ladder filter. This method is an effective method for broadening the band width in the first filter 103 of the branching filter having a relatively low passband. However, in the second filter 104 side having a relatively high passband, the amount of attenuation at a low frequency side, that is, the amount of attenuation in the passband of the other side filter, i.e., the filter 103, is degraded, and as a result, this method described above cannot be used. In addition, as a method for broadening the passband of the second filter 104 of the

branching filter having a relatively high passband toward a high frequency side, a method for broadening the band width may be mentioned in which inductance elements are added in parallel to series arm resonators of the ladder filter. However, by this method, the inductance elements thus added for broadening the passband of the ladder filter to a high frequency side cause the mutual induction therebetween, and as a result, it is difficult to ensure sufficient attenuation properties.

In a branching filter which is required to have a sufficient passband and attenuation properties, by simply decreasing the temperature coefficient of frequency TCF, it has been very difficult to satisfactorily obtain necessary passband width and amount of attenuation in a service temperature range.

In consideration of the conventional techniques described above, an object of the present invention is to provide a branching filter and a surface acoustic wave device suitably used therein, the branching filter capable of ensuring a sufficiently large band width and amount of attenuation in a service temperature range even when being used in a communication apparatus in which the spacing between the two passbands is small.

The branching filter of the present invention comprises a first filter with a relatively low passband, having a

first temperature property-improvement thin film; and a second filter with a relatively high passband, having a second temperature property-improvement thin film, in which the thickness of the first temperature property-improvement thin film is different from that of the second temperature property-improvement thin film so that the temperature coefficient of frequency of the first filter is larger than that of the second filter.

In accordance with one aspect of the branching filter according to the present invention, the first filter and the second filter are formed of surface acoustic wave filters.

In accordance with another aspect of the branching filter according to the present invention, the first filter and the second filter are piezoelectric thin-film resonance filters.

In accordance with another aspect of the branching filter according to the present invention, the surface acoustic wave filters are each formed using a piezoelectric substrate composed of a $LiTaO_3$ substrate or a $LiNbO_3$ substrate, and the first and the second temperature property-improvement thin films are each formed of a SiO_2 film provided on the piezoelectric substrate.

In accordance with another aspect of the branching filter according to the present invention, the thickness of the SiO_2 film provided for the first filter is larger than

that of the SiO_2 film provided for the second filter.

In accordance with another aspect of the branching filter according to the present invention, when the wavelength of the first filter is represented by $\lambda 1$, the thickness of the SiO_2 film of the first filter is set in the range of 0.18 $\lambda 1$ to 0.38 $\lambda 1$.

In accordance with another aspect of the branching filter according to the present invention, when the wavelength of the second filter is represented by $\lambda 2$, the thickness of the SiO_2 film provided on the second filter is set in the range of 0.08 $\lambda 2$ to 0.28 $\lambda 2$.

In accordance with another aspect of the branching filter according to the present invention, the first filter and the second filter are ladder filters each having series arm resonators and parallel arm resonators.

In accordance with another aspect of the branching filter according to the present invention, at least one inductance element connected in series to one of the parallel arm resonators of the ladder filter forming the first filter is further provided.

In accordance with another aspect of the branching filter according to the present invention, at least one inductance element connected in parallel to one of the series arm resonators of the ladder filter forming the second filter is further provided.

In accordance with another aspect of the branching filter according to the present invention, the first filter and the second filter are formed on respective piezoelectric substrates and are formed as respective chip components.

In accordance with another aspect of the branching filter according to the present invention, the first filter and the second filter are formed using the same piezoelectric substrate and are collectively formed as a single chip component.

A surface acoustic wave filter of the present invention is a surface acoustic wave filter used as a reception filter of a branching filter, in which the surface acoustic wave filter is formed so that the temperature coefficient of frequency thereof is positive with respect to the change in temperature.

In accordance with one aspect of the surface acoustic wave filter according to the present invention, a piezoelectric substrate composed of a $LiTaO_3$ or a $LiNbO_3$ substrate, electrodes formed on the piezoelectric substrate, and a temperature property-improvement thin film of a SiO_2 film formed so as to cover the electrodes on the piezoelectric substrate are provided, and when the wavelength determined by an electrode cycle is represented by λ, the thickness of the SiO_2 film is set in the range of 0.3 λ to 0.38 λ so as to have a positive temperature

coefficient of frequency with respect to the change in temperature.

In the branching filter of the present invention, the thicknesses of the temperature property-improvement thin films of the first and the second filters are different from each other so that the temperature coefficient of frequency of the first filter having a relatively low passband is larger than that of the second filter. Hence, when the spacing in frequency between the passband of the first filter and that of the second filter is small, in the first filter having a relatively low passband, the variation in frequency at a high frequency side of the passband is increased, and as a result, a production yield may be degraded in some cases. However, according to the present invention, in the first filter, the change in frequency-temperature properties at a high frequency side of the passband is decreased, and in the second filter, the change in temperature properties at a low frequency side of the passband can be decreased. Hence, over a service temperature range, sufficient passband width and amount of attenuation can be ensured.

Hence, according to the present invention, as a branching filter used for application in which the spacing between the reception side frequency and the reception side frequency is small, a branching filter capable of satisfying

sufficient specification properties over a service temperature range can even be provided.

When the first and the second filters are each formed of a surface acoustic wave filter, the branching filter of the present invention can be miniaturized.

As is the case described above, when the first filter and the second filter are each formed of a piezoelectric thin-film resonator filter, the branching filter can be miniaturized.

When the surface acoustic wave filter is formed using a piezoelectric substrate composed of a $LiTaO_3$ or a $LiNbO_3$ substrate, and the first and the second temperature property-improvement thin films are SiO_2 films formed on the piezoelectric substrate, the temperature properties can be effectively improved by a simple structure.

When the thickness of the SiO_2 film provided for the first filter is larger than that of the SiO_2 film provided for the second filter, by simply changing the thicknesses of the SiO_2 films, the temperature properties of the first and the second filters can be easily adjusted.

When the thickness of the SiO_2 film of the first filter is set in the range of 0.18 $\lambda 1$ to 0.38 $\lambda 1$, the frequency-temperature properties of the first filter can be effectively improved.

In addition, when the thickness of the SiO_2 film

provided for the second filter is set in the range of 0.08 λ2 to 0.28 λ2, the temperature coefficient of frequency of the second filter can be effectively improved.

When the first and the second filters are formed of ladder filters each having series arm resonators and parallel arm resonators, by using ladder filters commonly used for this type of band filter, the branching filter of the present invention can be formed.

When at least one inductance element connected in series to one of the parallel arm resonators of the ladder filter forming the first filter is further provided, the first filter can be matched with the second filter.

As is the case described above, when at least one inductance element is connected in parallel to one of the series arm resonators of the ladder filter forming the second filter, the second filter can be easily matched with the first filter.

When the first and the second filters are provided on respective piezoelectric substrates and are formed as respective chip components, the structures of the first and the second filters can be easily optimized.

In addition, when the first and the second filters use the same piezoelectric substrate and are collectively formed as a single component, the branching filter of the present invention can be miniaturized.

Since the surface acoustic wave filter of the present invention is used as a transmission filter of a branching filter and is formed so that the temperature coefficient of frequency is positive with respect to the change in temperature, even when an electrical power is supplied at a high frequency side of the passband, the degradation in insertion loss is not likely to occur. Hence, an optimum surface acoustic wave filter as a transmission filter of a branching filter can be provided.

In particular, in the case in which the surface acoustic wave filter includes a piezoelectric substrate composed of a $LiTaO_3$ or a $LiNbO_3$ substrate, electrodes formed on the piezoelectric substrate, and a temperature property-improvement thin film of a SiO_2 film formed so as to cover the electrodes on the piezoelectric substrate, and in which when the wavelength determined by an electrode cycle is represented by λ, the thickness of the SiO_2 film is set in the range of 0.3 λ to 0.38 λ so as to have a positive temperature coefficient of frequency with respect to the change in temperature, the temperature coefficient of frequency TCF of the surface acoustic wave can be made positive, and the temperature coefficient of frequency of the branching filter can be decreased as a whole.

Brief Description of the Drawings

[Fig. 1] Fig. 1 is a circuit diagram showing a circuit

structure of a branching filter of one embodiment according to the present invention.

[Fig. 2] Fig. 2 is a view illustrating the change in frequency properties of a second filter of a branching filter, the change being caused by the change in temperature.

[Fig. 3] Fig. 3 is a view illustrating the frequency properties of first and second filters of a branching filter.

[Fig. 4] Figs. 4(a) and 4(b) are schematic views showing the structures of a first and a second filter, respectively, used in a branching filter of a first embodiment.

[Fig. 5] Fig. 5 is a view showing the positive change in temperature dependence of a surface acoustic wave device when the thickness of a SiO_2 film is changed.

[Fig. 6] Fig. 6 is a plan view showing an electrode structure of a surface acoustic wave resonator forming the surface acoustic wave filter used in the first embodiment.

[Fig. 7] Fig. 7 is a view showing the change in frequency properties of a first filter suppressed in example 1, the change being caused by the change in temperature.

[Fig. 8] Fig. 8 is a view showing the change in frequency properties of a second filter suppressed in example 1, the change being caused by the change in temperature.

[Fig. 9] Fig. 9 is a view showing the change in electromechanical coefficient of a surface acoustic wave device when the thickness of a SiO_2 filter is changed.

[Fig. 10] Fig. 10 is a view showing the change in frequency properties of a first filter formed in example 2, the change being caused by the change in temperature.

[Fig. 11] Fig. 11 is a view showing the change in frequency properties of a second filter formed in example 2, the change being caused by the change in temperature.

[Fig. 12] Fig. 12 is a schematic plan view illustrating a ladder filter used in a surface acoustic wave branching filter of an experimental example according to the present invention.

[Fig. 13] Fig. 13 is a view showing a circuit structure of the ladder filter shown in Fig. 12.

[Fig. 14] Fig. 14 is a surface cross-sectional view illustrating a piezoelectric thin-film resonator forming a part of the ladder filter shown in Fig. 12.

[Fig. 15] Fig. 15 is a schematic front cross-sectional view illustrating another example of a piezoelectric thin-film resonator.

[Fig. 16] Fig. 16 is a schematic front cross-sectional view illustrating still another example of a piezoelectric thin-film resonator.

[Fig. 17] Fig. 17 is a circuit diagram illustrating one example of a conventional branching filter.

Reference Numerals

1··· branching filter

2··· antenna terminal

3··· input terminal

11··· first filter

12··· second filter

12a··· input terminal

S11 to S13··· series arm resonator

P11, P12··· parallel arm resonator

L11, L12··· inductance element

C11··· capacitor element

S21 to S23··· series arm resonator

P21 to P24··· parallel arm resonator

L21··· inductance element

L22··· inductance element

C21, C22··· capacitor element

31··· piezoelectric substrate

32··· electrode

33··· first temperature property-improvement thin film

41··· piezoelectric substrate

42··· electrode

43··· second temperature property-improvement thin film

51··· piezoelectric thin-film resonator

52··· substrate

52a··· recess portion

53··· insulating film

54··· lower electrode

55··· piezoelectric thin film

56··· upper electrode

61··· ladder filter

62··· diaphragm

63, 65··· parallel arm resonator

64, 66··· series arm resonator

67··· upper electrode

68··· lower electrode

69··· upper electrode

70··· upper electrode

71··· piezoelectric thin-film resonator

72··· substrate

72a··· penetrating hole

81··· common electrode

Best Mode for Carrying Out the Invention

Fig. 1 is a view showing a circuit structure of a branching filter according to a first embodiment of the present invention.

A branching filter 1 of this embodiment has an input terminal 3 belonging to an antenna 2. To the input terminal 3, a first filter 11 and a second filter 12 are connected. The first filter 11 has a relatively low passband, and the second filter 12 has a relatively high passband. That is, in the branching filter 1, the first filter 11 and the second filter 12 are a transmission filter and a reception

filter, respectively.

In addition, in this embodiment, the first filter 11 is formed of a ladder filter having series arm resonators S11 to S13 and parallel arm resonators P11 and P12. Furthermore, between the parallel arm resonators P11 and P12 and the earth potential, inductance elements L11 and L12 are connected, respectively.

In addition, between the input terminal 3 and the series arm resonator S11, a capacitor element C11 is connected.

The second filter 12 has a ladder type circuit structure as is the first filter 11. That is, the second filter 12 has a plurality of series arm resonators S21 to S23 and a plurality of parallel arm resonators P21 to P24. In addition, an inductance element L22 is connected in parallel to the series arm resonator S23.

Between the input terminal 3 and an input terminal 12a of the second filter 12, an inductance element L21 is connected. Between the earth potential and a connection point provided between the input terminal 3 and the inductance element L21, a capacitor element C21 is connected. Between the earth potential and a connection point provided between the input terminal 12a and the inductance element L21, a capacitor element C22 is connected.

The capacitor element C 11 connected to the first

filter 11 is matching element. In addition, the inductance element L21 and the capacitor elements C21 and C22 are provided to match the second filter 12 with the first filter 11. That is, the inductance element L21 and the capacitor elements C21 and C22 form a matching circuit.

The feature of the branching filter 1 of this embodiment is that the first filter 11 and the second filter 12 have a first temperature property-improvement thin film and a second temperature property-improvement thin film, respectively, and the thicknesses thereof are different from each other so that a temperature coefficient of frequency TCF of the first filter 11 is larger than that of the second filter 12. Hence, by the structure described above, sufficient specification properties in a service temperature range can be obtained. Hereinafter, the details will be described.

In a surface acoustic wave filter and a piezoelectric thin-film resonance filter, fine electrodes or very thin electrode films are formed, and as a result, the electrical resistance is relatively high. Hence, when the environmental temperature is increased, the resistivity is changed, and as a result, there has been a problem in that a filter loss is increased. The change in properties of a filter caused by the change in temperature will be described with reference to Fig. 2.

Fig. 2 shows general frequency properties of this type of filter. A solid line A shown in Fig. 2 indicates the frequency property, and solid lines A1 to A3 show the states of the change in the frequency property A, which is caused by the change in temperature, by enlarging the scale of the vertical axis indicating the insertion loss. The solid lines A1, A2, and A3 indicate the properties in the passband at -30°C, 25°C, and +85°C, respectively, the properties being shown by enlarged values.

When the shift of the central frequency caused by the change in temperature is assumed not to occur at all, at a low frequency side of the passband, the degradation in loss caused by the increase in temperature is equivalent to that obtained when the frequency is shifted to a high frequency side as shown by an arrow B1 in Fig. 2, and at a high frequency side, the degradation is equivalent to that obtained when the frequency is shifted to a low frequency side as shown by an arrow B2.

Furthermore, in a branching filter in which a first filter having a relatively low passband and a second filter having a relatively high passband are provided in combination, when the spacing between the respective frequencies is extremely small, as the properties of a branching filter shown in Fig. 3, the temperature dependence of frequency at a high frequency side (indicated by an arrow

C) of the passband of the first filter may be decreased, and as for the second filter, the temperature dependence of frequency at a low frequency side (indicated by an arrow D) may be decreased. By the structure as described above, the variation in frequency of the branching filter, which occurs in production, can be decreased as a whole.

In the present invention, the amount of change in frequency caused by the change in temperature is decreased at the central frequency of the second filter having a relatively high passband as compared to that of the first filter having a relatively low passband, so that the variation in frequency of the branching filter is decreased as a whole.

In this specification of the present invention, the case in which the temperature coefficient of frequency is small indicates that, for example, -20 ppm is small relative to -10 ppm, and -5 ppm is small relative to +5 ppm. That is, it is to be clearly understood that a small temperature coefficient of frequency is not determined by the absolute value thereof, and that as the TCF is decreased toward a negative value side, the temperature coefficient of frequency is called small. Accordingly, "the temperature coefficient of frequency is larger" indicates that the temperature coefficient of frequency TCF has a more positive value.

Figs. 4(a) and 4(b) are schematic front cross-sectional views of the first filter 11 and the second filter 12, respectively, of the branching filter 1 according to the above embodiment.

The first filter 11 shown in Fig. 4(a) is a filter having a relatively low passband and, in this embodiment, is formed of a surface acoustic wave filter. The first filter 11 has the structure in which electrodes 32 such as an IDT electrode are formed on a piezoelectric substrate 31. In addition, a first temperature property-improvement thin film 33 is formed so as to cover the electrodes 32.

In this embodiment, the piezoelectric substrate 31 is formed of a $LiTaO_3$ substrate. In addition, the electrodes 32 are formed of electrodes primarily composed of Cu, and the first temperature property-improvement thin film 33 is formed of SiO_2.

The second filter 12 shown in Fig. 4(b) has the structure in which electrodes 42 such as an IDT electrode are formed on a piezoelectric substrate 41. A second temperature property-improvement thin film 43 is formed so as to cover the electrodes 42. Also in the second filter 12, the piezoelectric substrate 41 is formed of a $LiTaO_3$ substrate, the electrodes 42 are primarily composed of Cu, and the second temperature property-improvement thin film 43 is formed of SiO_2.

In this embodiment, with respect to $LiTaO_3$ having a negative temperature coefficient of frequency, the temperature property-improvement thin films 33 and 43, which are provided for improving the temperature properties, are each formed of SiO_2 having a positive temperature coefficient of frequency. In addition, as can be seen from Figs. 4(a) and 4(b), the thickness of the first temperature property-improvement thin film 33 provided for the first filter 11 having a relatively low passband is formed larger than that of the temperature property-improvement thin film 43 provided for the second filter 12 having a relatively high passband.

Fig. 5 is a view showing the relationship between the temperature coefficient of frequency TCF and the thickness of a SiO_2 film formed so as to cover the electrodes of a surface acoustic wave device.

As can be seen from Fig. 5, as the thickness of the SiO_2 film is increased, the temperature coefficient of frequency TCF is shifted to a positive side. That is, the temperature coefficient of frequency becomes larger.

As shown in Figs. 4(a) and 4(b), in this embodiment, the thickness of the first temperature property-improvement thin film 33 of the first filter 11 having a relatively low passband is relatively large, and the thickness of the temperature property-improvement thin film 43 of the second

filter 12 having a relatively high passband is relatively small. Hence, the temperature coefficient of frequency of the first filter 11 is made large, and the temperature coefficient of frequency of the second filter 12 is made small. Accordingly, in the branching filter as a whole, the temperature dependence of frequency is suppressed, and the variation in frequency can be decreased. In other words, the specification property in a service temperature range can be sufficiently ensured. The details will be described with reference to particular experimental examples.

(Example 1)

The branching filter 1 of the embodiment shown in Fig. 1 was formed by the following procedure. The first filter 11 is a transmission filter, and the second filter 12 is a reception filter. The branching filter 1 is a filter used in a system in which the filter band of the transmission side is 1,850 to 1,910 MHz, and the passband of the reception filter is 1,930 to 1,990 MHz.

In the above system, the frequency spacing between the passband of the transmission filter and that of the reception filter is very small, such as 20 MHz. Hence, both the first filter and the second filter are required to have steep filter properties, and in addition, superior temperature dependence of frequency is also necessary.

In particular, since the first filter 11 as the

transmission filter must use the passband of the reception filter 12 as an attenuation band, the steepness at a high frequency side of the passband of the first filter 11 must be enhanced, and in addition, improvement in temperature dependence at a high frequency side of the passband is strongly required.

On the other hand, since the second filter 12 as the reception filter must use the passband of the first filter 11 as an attenuation period, in addition to the enhancement of the steepness at a low frequency side of the passband of the second filter 12, improvement in temperature dependence at a low frequency side of the passband is also required. As the series arm resonators and the parallel arm resonators forming the first filter 11 and the second filter 12, surface acoustic wave resonators having the electrode structure shown in Fig. 6 were used. An electrode structure 51 shown in Fig. 6 has an IDT electrode 52 and reflectors 53 and 54 provided at two sided of the IDT electrode 52. The electrode structure 51 is formed on a piezoelectric substrate, so that one surface acoustic wave resonator is formed. As shown in Fig. 1, the first filter 11 has the series arm resonators S11 to S13 and the parallel arm resonators P11 and P12, and the second filter 12 has the series arm resonators S21 to S23 and the parallel arm resonators P21 to P24. These series arm resonators S11 to

S13, S21 to S23 and parallel arm resonators P11, P12, P21 to P24 are each formed of the above surface acoustic wave resonator.

In addition, the first filter 11 and the second filter 12 have the circuit structures shown in Fig. 1. Electrode parameters of the individual resonators of the first and the second filters are shown in Tables 1 and 2 below.

[Table 1]

	S11	P11	S12	P12	S13
DUTY	0.55	0.55	0.55	0.55	0.55
NUMBER OF STAGES	2	1	3	1	2
NUMBER of ELECTRODE FINGER PAIRS	200	120	200	120	200
CROSS WIDTH (μM)	40	100	40	100	40
NUMBER OF ELECTRODE FINGERS OF REFLECTOR	20	20	20	20	20
WAVELENGTH (μm)	2.0275	2.0682	2.0152	2.0682	2.0275

[Table 2]

	P21	S21	P22	S22	P23	S23	P26
DUTY	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NUMBER OF STAGES	1	2	1	2	1	1	1
NUMBER OF ELECTRODE FINGER PAIRS	40	120	100	120	100	120	40
CROSS WIDTH (μM)	40	40	40	40	40	40	40
NUMBER OF ELECTRODE FINGERS OF REFLECTOR	20	20	20	20	20	20	20
WAVELENGTH (μm)	1.9620	1.8890	1.9620	1.8890	1.9620	1.9300	1.9620

The electrostatic capacitance of the capacitor element C11 of the first filter 11 was set to 5 pF. In addition, the inductances of the inductance elements L11 and L12 were

set to 3 nH and 3 nH, respectively. Furthermore, the inductance of the inductance element L21 of the second filter 12 was set to 3 nH, the inductance of the inductance element L22 was set to 3 nH, the capacitance of the capacitor element C21 was set to 2 pF, and the capacitance of the capacitor element C22 was set to 2.5 pF.

In this example, the first filter 11 and the second filter 12 are collectively formed as a single chip component using the same 36° X propagating $LiTaO_3$ substrate. That is, on one $LiTaO_3$ substrate, a first circuit structure is provided. Since the above filters are formed as a single chip component, the branching filter 1 can be miniaturized.

The electrodes are each formed of an electrode primarily composed of Cu, and as described above, in the first filter 11 and the second filter 12, the first temperature property-improvement thin film 33 composed of SiO_2 and the second temperature property-improvement thin film 43 composed of SiO_2 are formed, respectively (see Figs. 4(a) and 4(b)). The formation of the SiO_2 film was performed by sputtering. In addition, the thickness of the SiO_2 film as the first temperature property-improvement thin film 33 of the first filter 11 was set to 0.35 $\lambda 1$, that is, 715 nm, when the average wavelength of the first filter 11 was represented by $\lambda 1$. The average wavelength is an average value of the wavelengths of the parallel arm resonators and

the wavelengths of the series arm resonators.

On the other hand, in the second filter 12, the thickness of the SiO_2 film as the second temperature property-improvement thin film 43 was set to 0.25 λ2, that is, 483 nm, when the average wavelength was represented by λ2.

The frequency-temperature properties of the first filter 11 and the second filter 12 of the branching filter 1 formed as described above are shown in Figs. 7 and 8, respectively.

In Figs. 7 and 8, properties shown in a lower side are important parts of the properties shown in an upper side and are shown by an enlarging the scale of the vertical axis. In addition, in Figs. 7 and 8, the frequency properties at temperatures of -30°C, 25°C, and 85°C are shown.

Since the second filter 12 is a reception filter, the amount of attenuation must be ensured in the passband of the first filter 11 which is present at a low frequency side of the passband of the second filter 12. Hence, in the frequency properties of the second filter 12 shown in Fig. 8, superior temperature dependence of frequency must be ensured at a low frequency side of the passband.

On the other hand, the amount of increase in loss at a low frequency side of the passband caused by increase in temperature is equivalent to that of the change obtained

when the frequency is shifted to a high frequency side (see Fig. 2). Accordingly, when the temperature coefficient TCF of the central frequency of the second filter 12 is set to approximately -7 ppm/°C, the amount of frequency shift of the second filter 12 at a low frequency side caused by the change in temperature can be made approximately zero.

In addition, as shown in Fig. 7, the first filter 11 is a transmission filter, and the amount of attenuation thereof must be sufficiently increased in the passband of the reception filter which is present at a high frequency side of the passband of the first filter 11, and in particular, a superior temperature dependence of frequency must be ensured at a high frequency side of the passband. As shown in Fig. 2, the amount of increase in loss at a high frequency side of the passband caused by increase in temperature is equivalent to that of the change obtained when the frequency is shifted to a low frequency side. Accordingly, in the first filter 11, when the temperature dependence of the central frequency is selected to be approximately +7 ppm/°C, the amount of frequency shift at a high frequency side can be made approximately zero.

In addition, in Fig. 9, the change in electromechanical coefficient of this type of surface acoustic wave filter is shown which is obtained when the thickness of the SiO_2 film is changed. When the thickness of the SiO_2 film is

increased, due to the increase in mass, the electromechanical coefficient is decreased. Hence, as a result, it becomes difficult to sufficiently increase the band width of the filter. Accordingly, in this example, the inductance elements L1 and L12 are connected in series to the parallel arm resonators P11 and P12, respectively, of the first filter 11, and hence the band width is increased thereby.

In addition, the inductance element L22 is connected in parallel to the series arm resonator S23 of the second filter 12, so that the band width of the second filter 12 is also increased.

As a result, in the branching filter 1 of this example, as described above, the temperature dependence of frequency is decreased to approximately zero as a whole, the variation in frequency properties in a service temperature range is not liable to occur, and furthermore, the band widths of the respective filters 11 and 12 are sufficiently increased. Hence, in the service temperature range, the specification properties can be satisfactorily fulfilled.

In this example, as the piezoelectric substrate, the 36° $LiTaO_3$ substrate was used; however, for example, a $LiTaO_3$ substrate having another cut angle such as 42° $LiTaO_3$ substrate may also be used. Furthermore, a $LiNbO_3$ substrate may also be used which has been known as a substrate having

the effect equivalent to that of a $LiTaO_3$ substrate.

Furthermore, a material for the electrode is not limited to a material primarily composed of Cu, and a material primarily composed of another metal such as Al may also be used.

In addition, as the first and the second temperature property-improvement thin films, SiO_2 films are used; however, the temperature property-improvement thin films may be formed of another material. Furthermore, the first and the second temperature property-improvement thin films may be formed of materials different from each other.

(Example 2)

A branching filter was formed in the same manner as that in example 1. However, in example 2, the thickness of the SiO_2 film as the first temperature property-improvement thin film 33 of the first filter 11 was set to 0.25 $\lambda 1$, that is, 515 nm, and the thickness of the SiO_2 film provided for the second filter 12 was set to 0.15 $\lambda 2$, that is, 290 nm. The rest of the structure was the same as that in example 1.

Fig. 10 is a view showing the change in frequency properties of the first filter 11 of example 2 caused by the change in temperature, and Fig. 11 is a view showing the change in frequency properties of the second filter 12 caused by the change in temperature.

It is understood that the change of the central

frequency of the first filter 11 is approximately -7 ppm/°C, and that the change of the central frequency of the second filter 12 is approximately -20 ppm/°C.

At a high frequency side of the passband, since the amount of change in loss component caused by the increase in temperature works toward a negative side, it is understood that the temperature dependence of frequency of the passband of the first filter 11 shows approximately -14 ppm/°C at a high frequency side.

On the other hand, at a low frequency side of the passband, since the amount of change caused by the increase in temperature is equivalent to that obtained when the frequency is shifted to a high frequency side, the temperature dependence of the frequency properties is decreased to -14 ppm/°C as is the case of the first filter 11.

Hence, it is understood that when the thickness of the SiO_2 film is relatively increased at the first filter 11 side, the temperature dependence at a high frequency side of the passband of the first filter 11 and that at a low frequency side of the passband of the second filter 12 can be made approximately equivalent to each other. In example 2, compared to the case of example 1, although the temperature coefficient of frequency is slightly increased, in both the first filter 11 and the second filter 12,

temperature dependences which are approximately equally suppressed can be obtained. Hence, in production, a desired branching filter can be provided by easily combining a transmission filter and a reception filter with each other, both of which have temperature dependences approximately equivalent to each other.

In addition, in order to decrease the temperature coefficient of frequency, when the thickness of the SiO_2 film is too much increased, a problem as shown in Fig. 9 may arise in that the electromechanical coefficient is decreased. In example 2, since appropriate temperature property-improvement effect and electromechanical coefficient can be obtained, a branching filter having more superior frequency properties at room temperature can be provided. In particular, in example 2, when the thickness of the SiO_2 film as the second temperature property-improvement thin film provided for the second filter is set in the range of 0.08 $\lambda 2$ to 0.28 $\lambda 2$, the temperature dependence of frequency of the second filter can be improved at a low frequency side. In addition, when the thickness of the SiO_2 film as the first temperature property-improvement thin film provided for the first filter is set in the range of 0.18 $\lambda 1$ to 0.38 $\lambda 1$, the temperature dependence of frequency of the first filter as a transmission filter can be improved at a high frequency side of the passband.

In the embodiment described above, the first filter 11 and the second filter 12 are each formed of a surface acoustic wave filer; however, the first filter 11 and the second filter 12 are not limited to a surface acoustic wave filter and may be formed using other filters. That is, an appropriate filter having a temperature property-improvement thin film may be used as the first and the second filters. As the filters described above, for example, a piezoelectric thin-film resonator filter may be mentioned.

Fig. 12 is schematic plan view showing a ladder filter formed by using a plurality of piezoelectric thin-film resonator filters, and the circuit structure of this ladder filter is shown in Fig. 13.

In addition, Fig. 14 is a front cross-sectional view showing one piezoelectric thin-film resonator forming the ladder filter.

As shown in Fig. 14, a piezoelectric thin-film resonator 51 is formed using a substrate 52 having a recess portion 52a opened to the upper side. An insulating film 53 is laminated so as to cover this recess portion 52a. Then, on the insulating film 53, a lower electrode 54, a piezoelectric thin film 55, and an upper electrode 56 are laminated, so that a diaphragm is formed. The piezoelectric thin film 55 is formed of an appropriate piezoelectric material such as titanate zirconate lead ceramic, ZnO, or

AlN. The electrodes 54 and 56 are formed of an appropriate metal or alloy such as Al or Ag. The polarization axes of the piezoelectric thin film 55 are aligned in the thickness direction. Hence, when a voltage is applied from the electrodes 54 and 56, the piezoelectric thin film 55 is allowed to oscillate. In this case, since the laminate structure is provided on the recess portion 52a of the substrate 52, the oscillation of the piezoelectric thin film 55 is not inhibited, and as a result, resonance properties which can be used in a high frequency band is obtained. The substrate 52 may be formed using an appropriate insulating or semiconductor material such as a Si substrate. In addition, the insulating film 53 may also be formed using an insulating material such as Al_2O_3, SiO_2, or AlN.

Fig. 12 is a schematic plan view of a ladder filter having a two-stage structure formed using a plurality of piezoelectric thin-film resonators described above. In Fig. 12, the piezoelectric thin films are not shown. In a ladder filter 61, a part surrounded by a dotted line forms a diaphragm 62. That is, the diaphragm 62 indicates an upper part of the recess portion 52a of the piezoelectric thin-film resonator 51, that is, indicates an oscillation part. In this diaphragm 62, two parallel arm resonators 63 and 65 and two series arm resonators 64 and 66 are provided. In more particular, in the ladder filter 61, a lower electrode

68 is provided so as to be connected to the ground potential. In addition, an upper electrode 67 is connected to an input terminal. An upper electrode 69 is connected to the ground potential. In addition, an upper electrode 70 is connected to an output terminal. Hence, the ladder filter having a two-stage structure shown in Fig. 13 is formed.

In the piezoelectric thin-film resonator 51 shown in Fig. 14, the recess portion 52a opened to the upper side is provided in the substrate 52; however, as shown in Fig. 15, a piezoelectric thin-film resonator 71 may also be used using a substrate 72 having a penetrating hole 72a, the diameter of which is increased toward the lower side. In this case, the insulating film 53 is laminated so as to cover the upper opening of the penetrating hole 72a. In addition, on the insulating film 53, the lower electrode 54, the piezoelectric thin-film 54, and the upper electrode 56 are laminated, so that the diaphragm is formed.

Furthermore, as shown in Fig. 16, a common electrode 81 may be formed at the lower side of the insulating film 53 so as to face a pair of lower electrodes 54 with the insulating film 53 provided therebetween. In this case, the upper electrode 56 faces the pair of lower electrodes 54, so that a pair of resonator portions is formed. In addition, between the common electrode 81 and the lower electrodes 54, respective capacitors may be formed. As described above, a

piezoelectric thin-film resonator incorporating the capacitors formed of the common electrode 81 and the lower electrodes 54 may be used for forming the ladder filer described above.